

GROWTH RATE OF AILSA CRAIG SLOW-WORMS *ANGUIS FRAGILIS*: PREY PREFERENCE AND TEMPERATURE EFFECTS

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ABSTRACT

Slow-worms are abundant at lower altitudes on the island of Ailsa Craig (Firth of Clyde). They attain remarkable lengths: one male at 51.8 cm is the longest recorded in the UK. Most are found under metal and wooden sheet refuges, where congregations of about 40 individuals are common. Continuous temperature records in these refuges show significantly higher than ambient day-time temperatures. Prey choice experiments showed no size preference for slugs over a range of about 0.5-2.5g. Slow-worms kept at 27-28°C ate more and grew faster than slow-worms kept at 18°C.

Keywords: Ailsa Craig, slow worm, *Anguis fragilis*, growth and temperature, prey preference

INTRODUCTION

The slow-worm *Anguis fragilis* is probably one of the UK's commonest reptiles. There are no reliable population estimates for UK reptiles, but recorded sightings of slow-worms show a widespread distribution with most records in England being in the south, especially the south east, but in Scotland mainly in the south-west (Beebee and Griffiths, 2000). The slow-worm's fossorial habits contribute to our relative lack of knowledge both of this reptile's distribution and its ecology and habits. To understand this animal better, we need a good study site. One such is the island of Ailsa Craig which lies in the Firth of Clyde, 16 km west of Girvan. Ailsa Craig was designated a site of Special Scientific Interest in 1984, then a Specially Protected Area in 1990 and has now (2004) become a Royal Society for the Protection of Birds Reserve by agreement with the owner, the Marquis of Ailsa. The island's main interest is the vast populations of sea-birds which nest on its cliffs, but since a rat eradication programme in the early 1990s, it has become apparent that the island supports a considerable variety of fauna and flora (Zonfrillo, 1994). The first report of slow-worms on the island dates from the 1800's (Lawson, 1888); they were severely affected by the rat population, but, since the eradication, Zonfrillo (2000; personal communication) has noted not only that slow-worms are abundant but also that some individuals have attained remarkable sizes.

The aims of the work reported here were:

- To assess the sex ratio and sizes of slow-worms found in refuges on Ailsa Craig.
- To measure the temperature in slow-worm refuge sites
- To test prey size preference in slow-worms
- To measure slow-worm growth rate at different temperatures

MATERIALS AND METHODS

Visits to study site Ailsa Craig was visited on 17th June, 22nd July, 28th August and 11th October 2003. Each visit required a boat trip of 1.5h there and back, with 2-3h field-work on the island. Round much of Ailsa Craig, sheer cliffs face directly on to the sea, but on the east of the island, there is a relatively flat raised beach, rocky and shingly close to the sea, but well vegetated further on shore, rising steeply to a higher level. It is on the vegetated area that the light-house, disused quarry works and mainly ruined village are located (Fig. 1). Around the only habitable cottage, Dr Bernard Zonfrillo has placed a number of corrugated iron and plywood sheets to act as slow-worm refuges. Each visit, these sheets were lifted to sample slow-worms.

Slow-worm sampling An original aim of this study was to estimate population size, using the technique of mark and recapture. Since there is no effective marking technique for slow-worms, we hoped to use photographs of the unique head parietal pattern to identify individuals (Riddell, 1997); unfortunately, our camera had insufficient resolution and this aim had to be abandoned.

Since the number of slow-worms under each sheet could be around 30-40, some fully exposed, some half-burrowed, it was not practicable to count total numbers in each refuge: they lie closely entwined and can burrow remarkably quickly. Our method therefore was to lift a sheet quickly and pick up as many slow-worms as we could and transfer them to a bucket. We took them for measuring, then returned and collected a second sample from the same refuge. All slow-worms were replaced under their original refuges after measuring, except those taken to the laboratory for feeding experiments (see later). In addition to sampling regularly under

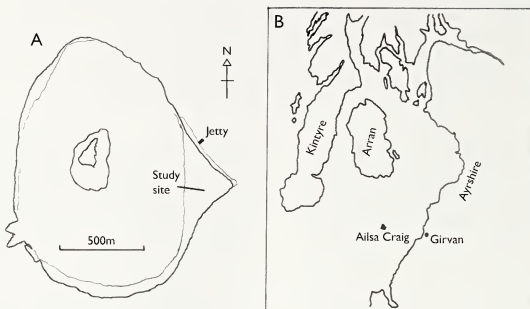


Fig. 1 Study site map and location (re-drawn from Zonfrillo, 1994). A: sketch map of Ailsa Craig, showing location of study site on flat area to south of jetty; B: location of Ailsa Craig.

the metal and wooden refuges, we used a line transect technique to assess the presence of slow-worms further from the cottage.

Slow-worm measuring and sexing On Ailsa Craig, slow-worms were weighed in bags using a Pesola spring balance accurate to 0.1g; in the laboratory they were weighed in closed polythene tubs using a digital balance to 0.01g. To measure length, slow-worms were straightened and held straight by one observer (this is not easy!) while the other assessed length to 0.1 cm using a meter stick. Individuals were sexed by the criteria of Beebee and Griffiths (2000): females have a dark dorsal stripe and are generally dark in colour; males lack the dorsal stripe and have a lighter uniform colour. Juveniles are not easily distinguished and even some larger individuals were unclear.

Field temperatures Gemini data loggers ('Tinytalks') were used to measure field temperature from 17th June to 11th October. These loggers are accurate to 0.1°C and were set to measure temperature every 2h i.e. 12 times a day. Loggers were sealed in polythene bags to protect them from excessive moisture. One was located under a corrugated iron refuge; another under a plywood refuge; the third was placed in a sheltered but not shaded site on the ground surface near the cottage. The information recorded was later downloaded onto a computer and analysed using Gemini software.

Laboratory experiments Samples of slow-worms from Ailsa Craig were taken to our laboratory at the University of Glasgow as follows: 17th June – 13 slow-worms, varying

sizes, both sexes (returned 28th August); 22nd July – 4 slow-worms (returned 11th October); 28th August – 10 slow-worms (returned 11th October).

Each slow-worm was maintained individually in a plastic tank 34x18x17 cm with a tight-fitting lid containing narrow air slits. Tanks were filled to 8–10 cm deep with moist peat. A water bowl was placed on each tank, the top flush with the peat surface. The peat was re-wetted weekly.

To feed the slow-worms, slugs were collected regularly from allotments, gardens and damp walls round the west end of Glasgow. We did not attempt to discriminate between species of slugs. Runham and Hunter (1970) note the difficulties of distinguishing the species of slugs on external characteristics: from their descriptions, *Agriolimax reticulatus* is likely to have been the commonest species in our collections.

Slow-worm tanks were kept in two rooms a) an unheated laboratory with natural lighting; temperature about 19°C. b) a temperature-controlled room at 27.5–28.5°C, with a 12h light:dark cycle.

Prey size preference experiment The 13 slow-worms collected on 17th June were fed twice a week for 5.5 weeks with one large (>2g), three medium (1–2g) and three small (<1g) slugs. Before each feed, slow-worms were measured and the tanks checked for uneaten slugs. The summer was unusually hot and dry for Glasgow, and slugs were sometimes very hard to find. Occasionally, therefore, it was not possible to provide the normal slug ration. This experiment was in the 19°C laboratory.

Temperature and growth experiment The 10 slow-worms collected on 28th August were divided into two groups, one kept in the 19°C laboratory and the other in the 27–28°C room. Each slow-worm was fed 8–9 g of slugs (randomly mixed sizes) twice a week. Before each feed, slow-worms were measured and the tanks checked for uneaten slugs which were weighed collectively and replaced in the tank. During this experiment, there was cooler, damper weather and the slug supply was adequate for our needs.

RESULTS

Population data Lengths and weights of animals in the June–August samples are shown in Table 1 (too few were measured in October for analysis).

Table 1 Morphometric data on Ailsa Craig slow-worms found under refuges. Lengths and weights given as mean \pm SD with range in brackets.

Date		Males	Females
17/6/03 ¹	N	23	10
	Length (cm)	38.0 \pm 7.2 (22.0–1.8)	39.3 \pm 7.4 (24.1–46.1)
	Weight (g)	27.5 \pm 10.9 (12.0–9.3)	29.0 \pm 11.8 (6.5–44.5)
22/7/03 ¹	N	14	10
	Length (cm)	35.6 \pm 8.0 (22.3–6.4)	35.2 \pm 8.9 (21.1–42.9)
	Weight (g)	30.7 \pm 12.7 (5.0–52.0)	25.7 \pm 14.4 (4.5–41.5)
28/8/03 ¹	N	11	19
	Length (cm)	38.0 \pm 7.0 (26.6–7.3)	33.3 \pm 10.5 (18.9–6.4)
	Weight (g)	30.6 \pm 13.1 (14.1–8.3)	22.4 \pm 13.4 (3.3–44.8)

¹ 17/6/03 Two males excluded from length and weight analysis because tails were shed on capture; 22/7/03 two males and one female excluded; 28/8/03 one female excluded.

The sex ratio in the June–August samples was significantly biased towards males in June ($X^2 = 5.12$; $P < 0.05$) but the ratios were not significantly different from 1:1 in the other months. The lengths and weights of the animals were very variable, as can be seen from the high standard deviations, and means were considerably affected by the proportion of smaller slow-worms sampled. The longest slow-worm found was 51.8 cm (weight 46.5 g) and the heaviest 52.0 g (length 46.4 cm), both males. We found no evidence for a difference in the length–weight relationship between males and females (data not shown), but our

sample size was too small to detect any fine differences.

Slow-worms were examined for signs of tail regeneration (the regenerating tail has a blunt tip): over the four visits we found 8 males and only two females with regenerating tails (from their sizes, these were most likely different animals except for two males).

All but a few of the measured slow-worms were located under metal or wooden sheets in the cottage area. We attempted to assess slow-worm distribution by looking under rocks, within a metre of a 50 metre line extended in three random directions from the cottage. However because of the highly aggregated nature of the population, this method was not successful, depending entirely on whether or not the transect included a good refuge. Another method was to lift rocks randomly in a walk away from the cottage: this at least showed that slow-worms did occur as far as 200 metres south of the cottage, but only some rocks could be lifted, so this method could not be properly quantitative.

Habitat temperature records Temperature data collected by the Tinytalk loggers are shown in figure 2 and an analysis in Table 2. Daily temperature fluctuations were greatest under the metal sheet, exceeding 40°C on 8 occasions, and dropping to between 10 and 15°C most nights.

Under the plywood sheet, the temperature never exceeded 40°C, but did exceed 30°C on 9 occasions, also dropping to between 10 and 15°C at night. By contrast, even in what was an unusually warm dry summer, the logger on the grass surface only once recorded a daytime temperature over 25°C, and daily fluctuations were characteristically of the order of 5–10°C only.

Table 2 shows mean temperatures at different times of day in each of three months measured at the three different sites. Not unexpectedly, night temperatures were similar at all three sites and remained at a similar level through most of the summer, only beginning to decline in later September. The biggest inter-site and inter-month differences were in the period most influenced by solar radiation, 08.00–16.00h, with mean temperatures in the refuges considerably higher than on the grass surface (metal sheet: 6–7°C; plywood: 3.5–4.5°C July and August), even in September (3–3.5°C).

The middle time period, 16.00–24.00h, showed only small differences between the sites: with the site east-facing and in the shade of a steep hill, temperatures drop quickly once direct sunlight has passed.

Table 2 Analysis of three site temperature records: data are mean temperatures ($^{\circ}\text{C} \pm \text{SD}$) in different months at different times of day. Recordings were at 2h intervals each day of each month. Metal: metal sheet; Plywood: plywood sheet; Grass: grass surface.

Time range Month	Site		
	Metal	Plywood	Grass
July			
08.00-	22.9 \pm	21.0 \pm	16.6 \pm
16.00h	7.9	5.3	2.3
16.00-	17.4 \pm	17.4 \pm	15.9 \pm
24.00h	13.7	3.8	0.4
24.00-	13.6 \pm	13.7 \pm	14.0 \pm
08.00h	1.6	1.7	1.4
Aug.			
08.00-	24.1 \pm	20.8 \pm	17.1 \pm
16.00h	8.0	4.6	2.4
16.00-	18.3 \pm	16.6 \pm	16.5 \pm
24.00h	5.3	3.7	2.2
24.00-	13.1 \pm	12.6 \pm	14.3 \pm
08.00h	2.1	2.3	1.7
Sept.			
08.00-	18.1 \pm	17.4 \pm	14.5 \pm
16.00h	5.3	5.1	2.6
16.00-	14.0 \pm	13.1 \pm	13.5 \pm
24.00h	3.1	3.5	2.0
24.00-	11.6 \pm	10.7 \pm	12.3 \pm
08.00h	2.3	2.7	2.0

Prey size preference Early during this experiment, one slow-worm escaped and was not re-captured. We therefore obtained data for prey preference from 12 slow-worms, ranging in weight from 7-49g (Table 3). The largest slow-worms tended to eat all or nearly all the prey items offered, whereas smaller slow-worms ate 70-90% of prey. Using Spearman's rank order correlation, we found significant positive relationships between proportion of prey items eaten and slow-worm weight for each prey size class (large: $r = 0.61$, $P < 0.05$; medium: $r = 0.59$, $P < 0.05$; small $r = 0.78$, $P < 0.01$). There was no evidence for slow-worms showing prey size selectivity but there was evidence for differences in total prey taken, related to slow-worm size. It is worth noting that size change over the 5.5 weeks of the experiment was very variable between individuals but rather small for the population as a whole, especially in length (mean \pm SD percentage change for the population in weight was 3.2 ± 13.3 ; length 0.4 ± 2.4). The high standard deviations are the result of some individuals reducing in their weight or length while others increased.

Temperature and growth Over the 5 weeks of the experiment, the mean size changes for the two temperature groups are shown in Table 4.

Table 3 Dimensions at end of trial of slow-worms used in prey size preference experiment.

Animal number	Weight (g)	Length (cm)
1	40.1	46.1
2	49.4	49.4
3	14.8	33.8
4	7.6	24.7
5	34.8	42.5
6	12.8	32.5
7	31.2	42.9
8	27.5	42.5
9	32.2	44.1
10	40.3	43.2
11	15.8	34.4
12	24.2	38.4

Table 4 Size changes in slow-worms kept at two temperatures for 5 weeks and fed 16-18 g slugs each week.

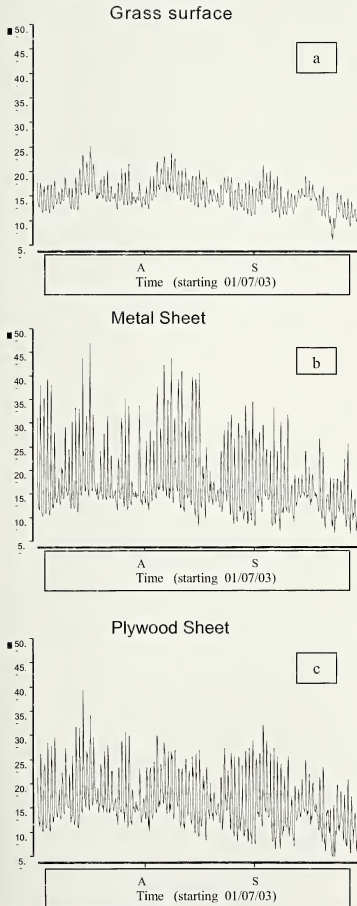
Temp. $^{\circ}\text{C}$	n	%size change (mean \pm SD)	
		Wt (g)	Lgth (cm)
19	5	-1.9 \pm 12.5	1.2 \pm 1.2
27-28	5	165.7 \pm 62.2	9.3 \pm 11.2

Table 5 Slug consumption in slow-worms kept at two temperatures for 5 weeks: data as mean \pm SD. Total slugs available, proportion of slugs consumed (%), and daily consumption (g).

Temp. $^{\circ}\text{C}$	n	slugs available (g)	slugs cons. (% wt)	daily cons. (g)
19	5	67.3 \pm 1.0	75.0 \pm 8.4	1.4 \pm 0.2
27-28	5	72.9 \pm 4.9	96.7 \pm 3.5	2.0 \pm 0.2

At the lower temperature, slow-worms grew hardly at all. At the higher temperature, growth was considerable but very variable. Weight tended to fluctuate considerably from week to week, probably relating to ingestion of food (and the relatively slow digestion rates in these ectothermic animals). Length was probably the more reliable measure of tissue growth. Figure 3 shows the relationship between length change and initial length at the two temperatures. Although the sample size is

Fig. 2 Daily fluctuation in temperature records (y axis), time starting (x axis, A = August, S = September) at three sites taken from Tinytalk dataloggers.
a) grass surface b) metal sheet c) plywood.



too small for statistical analysis, it seems clear that the larger slow-worms changed little at both temperatures, whereas the higher temperature allowed small slow-worms to grow rapidly.

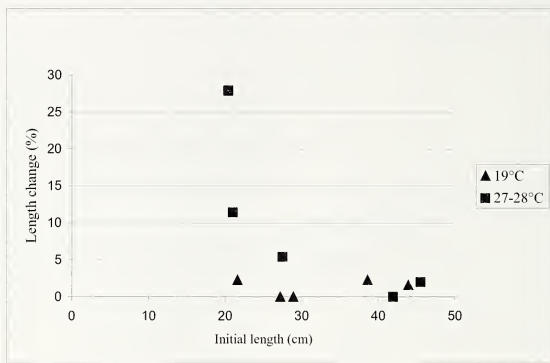
Slug consumption was very different in the two temperature groups: Table 5 summarises the results. Each slow-worm was fed a very similar slug ration twice a week, but if the slugs remaining from previous feeds exceeded the normal ration (8-9g), no extra slugs were provided. This only happened with the 19°C group, leading to a slightly lower mean ration over the 5 weeks. Daily consumption was significantly lower in this group, as was the percentage of ration consumed. On every occasion, slugs were left unconsumed by the slow-worms in this group, showing that the ration was in excess of their consumption capacity. However, in the 27-28°C groups, all slugs had been consumed on a total of 16 occasions (3.2 occasions per slow-worm over 9 samples), suggesting that this group could have consumed a few more slugs.

DISCUSSION

There are very few recent studies on the ecology of British slow-worms (Beebee and Griffiths, 2000, cite only four since 1980) and even fewer based in Scotland. This is the first study on the population based on Ailsa Craig, drawn attention to by Zonfrillo (2000). Beebee and Griffiths (2000) note that mainland slow-worms can reach 40.0 cm long, but that longer individuals have been reported from islands, with the "record" a 48.9 cm specimen from Portsmouth (Fairfax, 1965). However, Zonfrillo (2000) found one even longer in Ailsa Craig (49.0 cm) and we confirm the exceptional size of some Ailsa Craig individuals. One male was 51.8 cm (46.5 g) and seems to be the longest slow-worm reported from the UK. Furthermore, 50% of our June sample were over 40 cm in length. It is unclear what factors lead to these exceptional sizes. Longevity, abundant food resources and genetic factors may all be involved. Beebee and Griffiths (2000) note that females are longer than males at equivalent ages in some but not all populations. We were not able to determine ages, but did examine the length – weight relationship in the two sexes. There was no significant difference, but sample sizes were small and further data would be worth collecting.

Previous work (Patterson, 1990; Avery, 1995) has shown that slow-worms in the field are generally found under refuges such as pieces of metal, wood or rocks. This was also the case on Ailsa Craig, though it is impossible to

Fig. 3 Relationship between slow-worm length at the start of the experiment and length change after 5 weeks when kept at two temperatures, \blacktriangle = 19°C and \blacksquare = 27-28°C.



tell how many slow-worms were hidden in burrows when we took our samples. A mark-recapture study using individual head patterns as the 'mark' might answer the question. We also do not know how slow-worm location changed with time of day, since all our samples were taken around mid-day.

Most lizards bask in the sun to raise body temperature above ambient in order to promote their foraging speed and also digestive rate. On Ailsa Craig, common lizards, *Lacerta vivipara*, can be found basking on rocks near the shore (personal observations). The aggregation of slow-worms under refuges during the day suggests that they are mainly nocturnal foragers, which would correlate with the active time of their main prey, slugs, snails and earth worms (Luiselli, 1992). Slow-worms may use refuges to increase body temperature which would in turn promote food digestion and growth. Our temperature loggers showed that refuge temperatures during the middle of the day were well above normal surface temperatures. Indeed, on very hot days, temperatures under the metal sheet exceeded 40°C. In this context, it is interesting that Beebee and Griffiths (2000) report that slow-worms leave refuges when the temperature exceeds 35°C.

In our laboratory experiment on slug size preference using small, medium and larger slugs, we found no preferences, even in smaller slow-worms. However, we did not use very large slugs nor very small slow-worms, so there may be a preference related to slow-worm size outside the range we used.

Our second laboratory experiment, with slow-worms at two different temperatures and prey available in excess showed higher prey consumption at the higher temperature and significant growth, particularly in smaller slow-worms. This supports the adaptive value for slow-worms of seeking warm temperature refuges.

The abundance of slow-worms on Ailsa Craig makes this a particularly good location to study their ecology. Elsewhere, they are regarded as widespread but rarely common (Smith, 1991) and recent records for both common lizards and slow-worms in Scotland are very patchy (Bowles, 2002). A study with more field time on Ailsa Craig could be very valuable.

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